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Electricity transmission tariffs for large-scale wind power consumption in western Gansu province, China

Y.X. He*, M.Z. Zhu, W. Xiong, T. Zhang, X.L. Ge

School of Economics and Management, North China Electric Power University, Zhu Xin Zhuang, Bei Nong Lu No.2, Changping District, Beijing, China

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ABSTRACT

Large-scale wind power transmission presents the power system with several challenges. The determination of the transmission tariff and the cost-sharing issue are potential obstacles which may influence the development of wind power. This paper analyses the incremental cost to the power system for long-distance transmission of wind power, considers the fixed and variable properties of the incremental cost and the risk of fluctuations in the cost, and establishes a comprehensive risk-based pricing model for long-distance transmission of large-scale wind power electricity. Gansu Province in China has abundant wind resources, so we use the Jiuquan wind power integration and the ±800 kV Gansu-Zhuzhou direct current (DC) power transmission as examples to test the validity of the model. The conclusions are as follows: the allowances for access grid connection cost should be separately estimated for the large-scale wind power base and long-distance transmission; and the long-distance transmission pricing of large-scale wind power should apply a two-part electricity transmission pricing system, in order to eliminate the volatility risk inherent in each simple allocation method, and the fixed and variable characteristics of the transmission cost. The transmission price must include compensation for depreciation, operation and maintenance costs, and also a reasonable return on investment, in order to offer an effective incentive and guidance mechanism for enterprises' business development.

Contents

* Corresponding author. Tel.: +86 010 51963733; fax: +86 010 80796904.
E-mail addresses: yongxiuhe@126.com, heyongxiu@ncepu.edu.cn (Y.X. He).

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1. Introduction

With 7 GW wind power bases now being promoted, Chinese wind power development is switching to ultra-large-scale, high-concentration development and long-distance transmission, resulting in a greater than expected increase in transmission costs [1]. Currently, the Chinese transmission and distribution tariff has no clear independent pricing mechanism. It is mainly reflected by the difference between the retail tariff set by the government and the generation tariff also set by the government. However, with the acceleration of grid construction, the low transmission and distribution tariff seems increasingly contradictory. The consequence is that the electricity pricing mechanism cannot fully compensate the grid company, the power network cost cannot be incorporated into the retail tariff and the enthusiasm for wind power consumption is affected by the improper transmission and distribution tariff. In addition, the low transmission and distribution tariff is actually concealing inflation; this may dampen the enthusiasm of power investors and producers, causing a slowdown in grid construction, and continuous power supply tension, and finally affecting the security, stability, and ultimately the orderly and efficient operation of the grid system as a whole. The formulation of an allowance standard for wind power grid connection was based on the dispersive access model of traditional wind power. In fact, this standard was in line with the actual situation of wind power development at the time it was formulated, and it cannot fully meet the current and future demand for wind power development in China [2].

Currently, there are various transmission and distribution pricing methods. These include rolled-in transmission pricing methods, such as the postage stamp, MW-Mile, and contract path method. On this basis, Xia et al. [3] proposed a new transmission and distribution pricing method based on the optimal supply-demand match and MW Mile, to achieve a reasonable apportionment of distance-related transmission cost. Qiao et al. [4] calculated the share of use of the central China power grid through the analysis of trends and trading contracts. The other kind of pricing method is the marginal cost pricing method. Zhang et al. [5] priced each transmission line by using the marginal cost pricing method, and determining the transmission cost-sharing coefficient based on a power flow tracing method. Zhang et al., Reng et al. and Chung et al. [6–8] calculated the active power price and the reactive power price through using the marginal cost method, taking into account the recovery and investment of fixed assets, to ensure the grid's payment balance. Li et al. [9] calculated users' cost-sharing changes based on the marginal net loss coefficient method, calculated the additional cost by using the marginal cost method, and determined the users' cost by judging whether the marginal changes in the trading volume exceed the maximum capacity of devices. Tarjei Kristiansen [10] made a comparison of three transmission pricing models: the Wangensteen model, the optimal power flow model and the Hogan model, and found that three models have different applications: the Wangensteen model is used for educational purposes, the optimal power flow model has been widely used in electrical engineering and dispatch of power systems, and Hogan's model is an economist's version of the optimal power flow model. The studies above focus on conventional methods of transmission and distribution pricing. Although there are some differences in the transmission and distribution pricing mechanisms for renewable energy sources such as wind power, the studies above can also give some suggestions. For example, the recovery and depreciation of investment should be considered in wind power transmission and distribution pricing, and the power flow tracing method can be used to determine the transmission cost-sharing coefficients so as to ensure the power grid's payment balance.

At present, some scholars are studying large-scale wind power, as well as wind power grid connection pricing methods. Dale et al. [11] mainly studied the impact of long-distance large-scale wind power consumption on the operation cost, pointing out that the proportion of wind power in the power resource is closely related to the proportion of additional spare capacity provided for wind farms' rated capacity, and the reserve cost can be determined correspondingly. Swider et al. and Barth et al. [12,13] proposed three kinds of wind power cost-sharing methods: deep, shallow and ultra-shallow, which can give different definitions for the developers and the associated cost of power grid construction in wind power projects respectively. Hill et al. [14] studied the external issues of renewable energy pricing, and put forward the idea that the production cost of renewable energy electricity could be allocated for all energy products through reasonable tax collection and subsidies. Andrew et al. [15] studied the cost of transmission for wind power in the United States, developed a better understanding of the transmission costs and gained a better appreciation of the differences in transmission planning approaches. They concluded that the median cost of transmission from all scenarios is \$300/kW, roughly 15–20% of the cost of building a wind project. Abdala [16] mentioned that a number of elements should be used to set transmission prices on existing capacity, such as line losses, operating and maintenance costs, re-dispatching generation costs, network quality of supply and revenue reconciliation.

In summary, current studies on large-scale wind power transmission pricing methods mainly focus on the distribution of the additional cost caused by wind power grid integration, and the market mechanisms and fiscal policy which are adapted to it [17,18]. These studies discuss the impact of wind power grid integration on transmission and distribution links from different perspectives, but they have not taken into account that large-scale wind power base in Gansu Province is concentrated in economically backward regions which are far away from load centres. Therefore, the wind power needs to be transmitted long distances to load centres located in economically developed areas, which requires a large amount of construction investment, and the transmission cost will significantly increase correspondingly. Based on the incremental analysis, this paper examines the incremental cost to the electric power system caused by the long-distance transmission of large-scale wind power, considering the fixed and variable properties of that incremental cost, and the risk from cost fluctuations, to establish an electricity transmission pricing model based on the risk cost. It took the long-distance transmission of wind power in Gansu Province as an example to verify the validity of the model.

2. Cost and risks of long-distance transmission of wind power

The cost of electricity transmission can be divided into fixed cost and variable costs. A fixed cost is an expense that, under certain conditions, does not change with the transmission capacity, such as a depreciation cost, or operation and maintenance cost. A variable cost is one that changes with the transmission capacity, such as the network loss cost. Long-distance transmission of large-scale wind power is bound to bring the grid system increasing costs [19], specifically as follows:

2.1. Incremental fixed costs

Incremental fixed costs are those for long-distance transmission of wind power which do not change with the transmission capacity.

(1) Incremental depreciation cost. After power grid enterprises invest and construct projects for wind power generation and transmission, the fixed assets will be substantially increased, as will their depreciation cost. The depreciation cost is calculated by the grid enterprises according to the applicable depreciation rate of fixed assets.
(2) Incremental operation and maintenance cost. After the wind power projects are put into operation, their operation and maintenance costs will also be substantially increased.

2.2. Incremental variable costs

Incremental variable costs are those for long-distance transmission of wind power, which change with the transmission capacity.

(1) Incremental network loss cost. This is the cost of power loss from transmission lines and transformer loss, which increases with the transmission capacity. Large-scale wind power transmission is bound to increase the transmission capacity, which leads to an increase in the cost of network loss.
(2) Incremental variable costs which are associated with the variability of wind power output. Wind power output is uncontrollable, unpredictable and variable. This increases the cost of power system ancillary services such as reserve, peak shaving, and phase modulation. This cost increases with the proportion of wind power in the main power supply.

2.3. Risk analysis on fluctuations in the cost

The key factors that affect fluctuations in the cost of long-distance transmission of wind power are as follows:

(1) The volatility of wind power resources leads to a short-term and extensive fluctuation of wind power output. For system security, it needs to use more backup, interconnection and other methods to deal with the great volatility of the balance of electric power and energy. So the volatility of wind power resources leads to fluctuations in the variable costs which are associated with the variability of wind power output.
(2) After enterprises invest in projects for the construction of wind power facilities, this produces a substantial increase in the fixed assets, and also a corresponding increase in depreciation, as well as operation and maintenance, and other fixed costs. Therefore investment in fixed assets determines the amount of fixed costs. But once the investment is completed, the cost will turn into a sunk cost.
(3) The rates used for calculating depreciation and operation and maintenance costs from fixed assets are also factors that affect the cost. The higher the rates are, the more the fixed costs increase. However, the rates of depreciation and maintenance are determined by the enterprise according to the actual situation at the start of construction. Once established, the fluctuation risk is quite low.
(4) The uncertainty of the wind resource itself, as well as grid load and power system security, determines the uncertainty of wind power generation, with the result that the costs of network loss and power sharing both have fluctuation risks.

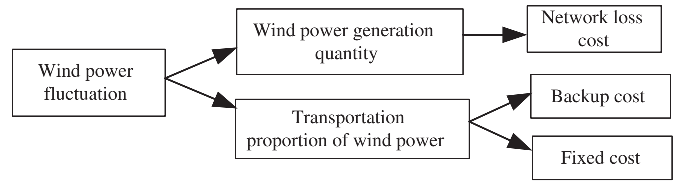

Fig. 1. Risk transfer chain of transmission cost fluctuation.

(5) The type of wind power and its ratio to other combined power supplies for long-distance transmission will directly affect the utilization of the delivery channel and the sharing costs.

In summary, the fundamental factor that affects fluctuations in the cost of long-distance transmission of wind power is the uncertainty of the wind resource. It is precisely because of this uncertainty that power companies have no choice but to consider increasing the reserve capacity, as well as joint delivery with other energy sources to ensure power reliability. Both the resulting fluctuations in wind power capacity and changes to the proportions of wind power and other energy sources in the combined transportation have a direct impact on changes in transmission costs. The risk transfer chain is shown in Fig. 1.

3. Comprehensive pricing model for long-distance transmission of wind power

3.1. Composition of electricity transmission and distribution tariff and pricing reform

The ‘‘Interim measures for electricity transmission and distribution pricing’’ promulgated by the National Development and Reform Commission (NDRC) in 2005 show the electricity transmission and distribution tariff as the general price of the services that grid enterprises provide, including access to the system, networking, power transmission and distribution services. The structure of the price system is shown in Fig. 2. Electricity transmission and distribution pricing reform in China can be divided into three steps: purchase and retail of electricity difference pricing, ‘‘cost plus return’’ pricing and incentive performance-based pricing. The first step has been carried out, and the latter two steps are the directions being taken in the development of transmission and distribution pricing.

3.2. Wind power connection cost model

3.2.1. Wind power connection cost allowance in China

In 2007, NDRC promulgated the ‘‘Interim measures for additional renewable energy revenue allocated’’, in which the method of allocating the connection cost is based on the traditional distributed access model. The connection cost allowance standard for renewable energy projects is established by the length of transmission lines: 50 km at 0.01 Yuan/kW h, 50–100 km at 0.02 Yuan/kW h, 100 km and more at 0.03 Yuan/kW h.

The state has not completed the relevant provisions covering project investment, operation and maintenance and other aspects of wind power and other renewable energy generation accessing systems. And this lack of provision has affected the enthusiasm of power grid enterprises for investing in related projects. Wind power projects are usually far from the load centres. So the construction of access systems is quite a large requirement, and the investment is high, while line utilization is low.

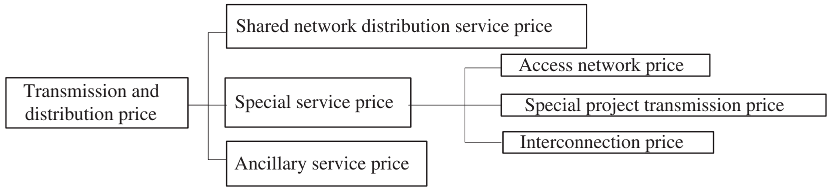

Fig. 2. Transmission and distribution pricing system structure.

The connection cost allowance standard does not meet all of the grid investment and operation and maintenance needs, which influences the enthusiasm and sustainable development of grid enterprises.

3.2.2. *Approved model of wind power connection cost*

The current method approved by the state to calculate the wind power connection cost is direct investment allocation with electricity quantity [2]. Using power generation as the unit of measurement only considers the one-time investment for connection of the wind farm, and does not take into account the operation and maintenance costs. So the connection cost allowance is not comprehensive, as it does not consider a reasonable return for the investment that the grid enterprises make. The grid connection fee is calculated as follows:

$$C_{oi} = \frac{I \times (1+r)^n \times r}{[(1+r)^n - 1] \times P_e \times T_{eq}} \tag{1}$$

where C_{oi} represents the grid connection cost, I represents the initial investment in access grid project, P_e represents the installed capacity of wind power, T_{eq} represents the equivalent annual operating hours at full load, r represents the discount rate, n represents the depreciation life of access grid channels.

According to "Interim Measures for electricity transmission and distribution pricing in China", the price should be determined gradually through the "cost plus return" pricing method, using permitted revenue. As an important component of the electricity transmission and distribution pricing system, the reasonable method to calculate the grid connection price should also use the approved tariff revenue, namely the "cost plus return" pricing method, which is shown in formula (2):

$$C_{oi} = \frac{R_{acc\text{-}net}}{G_{wind}} = \frac{C_{acc\text{-}net} + E_{acc\text{-}net} + T}{G_{wind}} \tag{2}$$

where C_{oi} represents the grid connection cost, $R_{acc\text{-}net}$ represents the permitted revenue of access grid project, G_{wind} represents the quantity of wind power generation, $C_{acc\text{-}net}$ represents the permitted cost, including depreciation, operation and maintenance costs, $E_{acc\text{-}net}$ represents the permitted return and T represents taxes.

Permitted return and weighted average cost of capital are calculated as formulas (3) and (4) as follows:

$$E_{acc\text{-}net} = A_{val} \times C_{aver\text{-}cap} \tag{3}$$

$$C_{aver\text{-}cap} = K_{equ\text{-}cap} \times (1 - T_{ass\text{-}lia}) + K_{deb\text{-}cap} \times T_{ass\text{-}lia} \tag{4}$$

where A_{val} represents the effective asset, $C_{aver\text{-}cap}$ represents the weighted average cost of capital, namely permitted rate of return, which can be understood as the permitted return in the unit of assets of access grid project, $K_{equ\text{-}cap}$ represents the cost of equity capital, $K_{deb\text{-}cap}$ represents the debt capital cost, $T_{ass\text{-}lia}$ represents the asset–liability ratio.

3.3. *Comprehensive risk-based transmission pricing model for large-scale long-distance transmission of wind power*

3.3.1. *Transmission cost allocation model*

The long-distance transmission cost allocation models of wind power are as follows:

Model 1: apportioned by transmission quantity of electricity

$$P^1_{trans} = \frac{C_{total}}{G_{wind}} \tag{5}$$

where P^1_{trans} represents the transmission price of wind power, C_{total} represents the transmission cost, G_{wind} represents the transmission quantity of electricity.

Model 2: apportioned by installed capacity of wind power

$$P^2_{trans} = \frac{C_{total}}{O_{wind}} \tag{6}$$

where P^2_{trans} represents the transmission price of wind power, O_{wind} represents the installed capacity of wind power.

Model 3: apportioned partly by capacity and partly by quantity

$$\begin{cases} P^3_{trans\text{-}G} = \frac{k_{ger} \times C_{total}}{G_{wind}} \\ P^3_{trans\text{-}O} = \frac{k_{cap} \times C_{total}}{O_{wind}} \end{cases} \tag{7}$$

where $P^3_{tran\text{-}G}$ represents part of transmission cost of wind power which is apportioned by transmission quantity of electricity, $P^3_{tran\text{-}O}$ represents left transmission cost of wind power which is apportioned by the capacity, k_{ger} represents the quantity sharing coefficient, that is the proportion of the transmission cost apportioned by transmission quantity of electricity, k_{cap} represents the capacity sharing coefficient.

Comparing the three cost allocation models above, model 1 is completely apportioned according to the transmission quantity of electricity. Due to the fluctuation risk in the quantity, the fluctuation risk in the fixed cost must increase with the quantity allocation, as does the business risk for the grid enterprises. Model 2 considers the cost apportioned only according to the installed capacity. Although it can secure a reasonable recovery of fixed costs through the capacity, the fluctuation risk in variable costs cannot be offset by the electricity quantity. It is not difficult to see that model 3 is a comprehensive model based on models 1 and 2, using sharing coefficients to make a reasonable division of cost, not only considering the fixed characteristics of the cost, but also avoiding the risk from fluctuations in wind power generation. This model is equivalent to a two-part pricing system. We consider using model 3 as the transmission cost allocation model.

3.3.2. *Transmission cost calculation model*

Considering the fixed and variable properties of the incremental cost and the risk of fluctuations in the cost, a comprehensive risk-based transmission pricing model for long-distance transmission of large-scale wind power is established as follows:

$$C_{total} = C_{st} + C_{va} \tag{8}$$

$$C_{st} = (k_{wind} + k_{risk}) \times (C_{depre} + C_{ope\text{-}main}) = (k_{wind} + k_{risk})$$

$$\times(I_{\text{trans}} \times r_{\text{depre}} + I_{\text{trans}} \times r_{\text{ope-main}}) \quad (9)$$

$$C_{\text{va}} = C_{\text{backup}} + C_{\text{loadlost}} = (O_{\text{backup}} + \lambda \times k_{\text{risk}}) \times C_{\text{cap}} + (G_{\text{wind}} + G_{\text{risk}}) \times r_{\text{loadlost}} \times C_{\text{trans}} \quad (10)$$

where C_{st} represents the fixed cost that wind power transmission tariff should apportion, including the depreciation cost C_{depre} and the cost of operation and maintenance $C_{ope\text{-}main}$, C_{va} represents the variable cost that wind power transmission tariff should apportion, including cost of ancillary services C_{backup} and the cost of network loss $C_{loadlost}$, k_{wind} represents the proportion of wind power of main power supply, k_{risk} represents the adjustment proportion value which take risk of cost fluctuations into account, I_{trans} represents the transmission projects investment, r_{depre} represents the comprehensive depreciation rate, $r_{ope\text{-}main}$ represents the rate of operation and maintenance, O_{backup} represents the backup capacity for wind power integration, C_{cap} represents the backup capacity cost per unit, λ represents the degree of influence that the proportion of wind power on the backup capacity, $r_{loadlost}$ represents the network loss rate, G_{wind} represents the transmission quantity of wind power, G_{risk} represents the adjustment electric quantity value which take risk of cost fluctuations into account, C_{trans} represents the network loss cost per unit.

3.3.3. Risk factors impact model

(1) Wind speed fluctuations probability density function
The fundamental factor that affects the fluctuation in the long-distance transmission cost of wind power is the intermittent, volatile and random wind resource. It can be quantified by the wind speed in order to consider its fluctuation risk. A two-parameter Weibull distribution curve is generally considered most suitable for the statistical description of the wind speed probability density function [20]. The probability density function is as follows:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (11)$$

where v represents the average wind speed of one section of wind speed, k and c represent two parameters of Weibull distribution, k is the shape parameter, c is the dimension parameter.

(2) Wind power fluctuation influence function on quantity of wind power generation
The wind power fluctuation varies in different wind source areas. Change of wind speed has a direct impact on wind power output, and so affects the amount of wind power generation. The wind power fluctuation influence function is shown as follows:

$$G_{\text{risk}} = -\sqrt[3]{\frac{\Delta v}{v}} \times G_{\text{wind}} \quad (12)$$

where G_{risk} represents the electric quantity influence value which take risk of wind speed fluctuation into account, Δv represents the change value of wind speed risk, v represents the basic wind speed.

(3) Wind power fluctuation influence function on proportion of wind power in total power.
The proportion of wind power in the joint transport with other energy sources is determined by the stability of the grid system, and the economy of joint delivery of energies. The smaller the wind speed variation is, the less impact wind power has on the stability of the power system, and then the proportion of wind power can be increased accordingly. The wind power fluctuation influence function on the proportion of wind power is as follows:

$$k_{\text{risk}} = -\frac{\Delta v}{v} \times k_{\text{wind}} \quad (13)$$

where k_{risk} represents wind power proportion influence value which take the risk of wind speed fluctuation into account, Δv represents the change value of wind speed risk, v represents the basic wind speed.

3.3.4. Comprehensive transmission pricing model

The wind power transmission cost calculation model above is completely based on the incremental cost, but according to "Interim Measures for electricity transmission and distribution tariff", it should instead use the "cost plus return" pricing method to determine the electricity transmission and distribution tariff. Therefore, consideration is given to adding a certain return into the transmission tariff model and the enterprises can compensate business operating costs and get a reasonable and fair rate of return. The comprehensive risk-based transmission pricing model for long-distance transmission of large-scale wind power is as follows:

$$\begin{cases} P_{\text{trans-}G} = \frac{k_{\text{ger}} \times (C_{\text{total}} + E + T)}{G_{\text{wind}}} \\ P_{\text{trans-}O} = \frac{k_{\text{cap}} \times (C_{\text{total}} + E + T)}{O_{\text{wind}}} \\ k_{\text{ger}} + k_{\text{cap}} = 1 \end{cases} \quad (14)$$

where $P_{tran\text{-}G}$ represents the transmission tariff apportioned by transmission quantity of electricity, $P_{tran\text{-}O}$ represents the transmission tariff apportioned by capacity, k_{ger} represents the electricity quantity sharing coefficient, k_{cap} represents the capacity sharing coefficient, E represents the permitted return and T represents taxes.

In general, the two-part transmission pricing system is composed of two parts: the first is the fixed costs that have nothing to do with the quantity of electricity transmission, known as the "capacity transmission price"; the second is determined by the quantity of electricity units, collected according to the amount of transmission power, referred to as the "electricity quantity transmission price." A model to determine the allocation coefficients can be assessed as follows:

$$\begin{cases} k_{\text{cap}} = \frac{C_{\text{st}}}{C_{\text{total}}} \\ k_{\text{ger}} = \frac{C_{\text{va}}}{C_{\text{total}}} \end{cases} \quad (15)$$

The transmission tariff is mainly used for recovery of the investment costs of the grid construction, and the variable costs are directly associated with the quantity of wind power electricity, the proportion of which is small. Using only the electricity quantity to apportion the variable costs will make the capacity price much higher than the quantity price. For the sake of risk aversion and to make the two-part tariff more balanced, we can take an appropriate increase in the allocation coefficient, such as considering the average share of fixed costs, that is

$$\begin{cases} k_{\text{cap}} = 50\% \times \frac{C_{\text{st}}}{C_{\text{total}}} \\ k_{\text{ger}} = 50\% \times \frac{C_{\text{st}}}{C_{\text{total}}} + \frac{C_{\text{va}}}{C_{\text{total}}} \end{cases} \quad (16)$$

The pricing model above is conducive to attracting investment, while ensuring the smooth progress of reproduction and encouraging the power companies to update the equipment for wind power generation.

4. Electricity transmission tariffs for large-scale wind power in western Gansu province

4.1. Basic data

Gansu Province is located in the upper reaches of the Yellow River, in the north-west of China. It is rich in wind energy resource, with an

estimated total resource of 237 GW, and the available area reaches 177 thousand square kilometers, mainly in the Hexi Corridor, including Guazhou and Jiuquan regions. The distribution of effective wind power density in Gansu Province is shown in Fig. 3. The exploitation of wind power in Gansu started in 1997. Since 2008, it has gone into a phase of rapid development. At the end of 2010, the scale of wind power in Gansu Province reached 1.45 GW. Since the beginning of 2011, the Jiuquan wind power base in Gansu province has entered a phase of high-speed development. At the end of June 2011, Gansu had invested in the construction of 35 wind power farms and its installed capacity had reached 4.15 GW.

In order to accommodate the first phase of the construction project in Jiuquan wind power base, the power grid companies built the 750 kV transmission project and expanded another main transformer for the 330 kV substation at Guazhou in Gansu Province. The power grid companies also constructed 229 km of 330 kV wind power transmission lines. The distance between the Jiuquan wind power base and the load center around Lanzhou is about 566 km. The total investment for these projects was 8.476 billion Yuan. The total funds that Gansu Power Grid Company invested in the wind collection and transmission project reached 9.101 billion Yuan.

The estimated parameters of the wind power tariffs for Gansu Power Grid Company, which relate to the cost-plus-return pricing, are shown in Table 1.

4.2. Calculation of the transmission tariff

4.2.1. Access network cost

The large-scale wind power in Guazhou and Jiuquan regions is transported through the 750 kV transmission line from Dunhuang to Yongdeng to connect with Gansu's main grid load centre. As shown in Fig. 3, the distance between Jiuquan wind power base and Yongdeng is more than 560 km. Therefore, the Gansu Power Grid Company must invest heavily in projects supporting the transmission of wind power. The investment for this series of projects should be credited to the Power Grid Company's costs for transporting the large-scale wind power, which means these investments should be included in the access network fees. According to the pricing model (2)–(4) of access network costs and the parameters in Table 1, the costs of the access network were calculated as shown in Table 2.

According to the results in Table 2, the access network cost is higher than the allowance standard (0.03 Yuan/kW h) that was established by the government. This is mainly because the program treats the load centre as the connection grid for wind power and treats the large-scale wind power access project as an overall investment. This program not only takes into account the Power Grid Companys costs for the connection of large-scale wind but also considers the investment in the transmission support project that helps to connect the wind farm with the main load centre. Because the investment cost is increasing, here we calculated the increase in the access network cost too.

4.2.2. Long-distance transmission tariffs for large-scale wind power

According to the comprehensive model (14) of transmission pricing and the sharing mechanism of the Two-Part Tariffs, which is the sharing coefficient formula (15), this paper calculated the allocated costs and the transmission pricing of the ±800 kW Gansu–Zhuzhou direct current (DC) power transmission line which will be built during the Twelfth Five-Year (2011–2015) period. In order to guarantee the security and stability of the power system during transmission, we considered the effect of the risk of wind power fluctuations on the cost and initially set the bundling rate of wind & thermal power as 1:6. The transmission tariff of the fixed costs is shown in Table 3.

The adjusted value transmission power tariffs that include the allocated variable cost and the power fluctuations are shown in Table 4. We initially set the network loss rate of the 750 kV transmission line as 2.11% to calculate the increase in the cost of

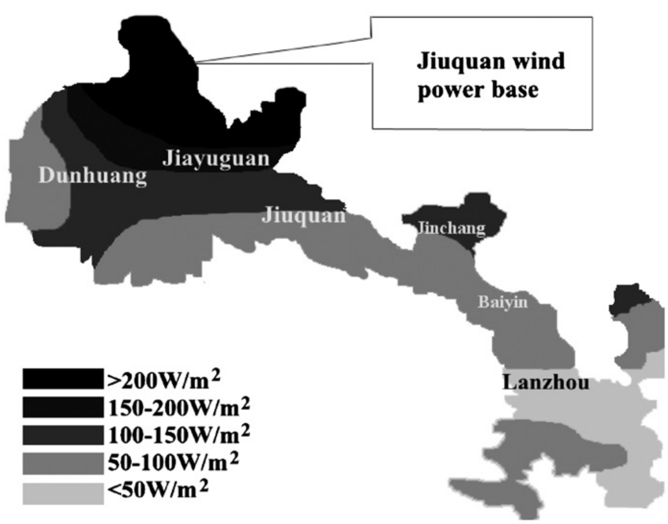

Fig. 3. The distribution of effective wind power density in Gansu province.

Table 2
Calculated result of access network costs.

No.	Item	Unit	Value
1	Permitted Revenue	Billion Yuan	1.468
1.1	Permitted cost	Billion Yuan	0.751
	Depreciation cost	Billion Yuan	0.556
	Operation and maintenance cost	Billion Yuan	0.196
1.2	permitted return	Billion Yuan	0.648
1.3	Taxes	Billion Yuan	0.068
2	Power that is measured by volume	Billion kW h	108.28
3	Estimated power grid connection costs	Yuan/kW h	0.136

Table 1
Estimated parameters.

Parameters	Values (%)	Remarks
Depreciation rate	8	The value is the consolidated depreciation rate of fixed assets of Gansu Power Grid Company in 2009
Operation and maintenance rate	2.50	The operation and maintenance costs are 2.5% of the fixed assets
Cost of debt	7.83	The value is the long-term interest rate which means more than five years
Cost of Equity	8	The Value is calculated by long-term bond rate plus 2% of the risk reward rate
Asset–liability ratio	80	20% of the capital is from their own and 80% comes from bank loans
VAT rate	17	These values are the current actual values
Income tax rate	25	
Urban construction rate	7	
Additional education rate	3	

Table 3
Capacity price for long-distance transmission.

No.	Item	Unit	Value
	Investment	Million Yuan	4923.08
1	Permitted revenue	Million Yuan	919.21
1.1	Permitted cost	Million Yuan	491.08
	Depreciation cost	Million Yuan	374.15
	Operation and maintenance cost	Million Yuan	116.92
1.2	Permitted return	Million Yuan	386.95
1.3	Taxes	Million Yuan	41.18
2	The capacity	GW	2.88
3	The tariff of volume power	Yuan/kW/month	26.55

Table 4
Electricity tariff for long-distance transmission.

Item	Unit	Value
The tariffs of line losses	Yuan/kW h	0.006645
The reserve costs	Yuan/kW h	0.029
The risk-adjusted value	Yuan/kW h	0.003
The tariff without risk factors	Yuan/kW h	0.035645
The tariff with risk factors	Yuan/kW h	0.038645

Table 5
Two-part tariff for wind power transmission.

Item		Unit	Value
The transmission tariffs for large-scale wind power with the risk of cost fluctuations	Capacity tariff	Yuan/kW h/month	13.28
	Electric quantity tariff	Yuan/kW h	0.11

network loss. According to research into the reserve cost, we assume the reserve cost is 0.029 Yuan/kW h.

As shown in Table 4, the variable cost is much lower than the fixed cost. Therefore using an improved sharing coefficient model (16), this paper elected to divide the fixed costs into two parts. One part was divided by the capacity sharing ratio of 1:6, and the other was divided by the power sharing ratio of 1:4. This model not only ensures the recovery of the investment in the transmission line, but also avoids the risk of wind power fluctuations to some extent and takes into account the fixed characteristics of the cost. The result is shown in Table 5.

According to the different sharing coefficient values, the comprehensive transmission pricing model can be used to work out transmission tariffs with different allocation methods. Combining capacity allocation and electricity quantity allocation can help to avoid the fluctuation risk that exists when only one kind of allocation method is considered, and also takes into account the fixed and variable characteristics of the cost. Therefore, this approach has strong operational characteristics and widespread applicability.

5. Conclusions

The study concludes that when designing an electricity transmission pricing model for large-scale wind power, it is necessary to consider the incremental cost to the power system of the long-distance transmission of wind power, and the fixed and variable properties of incremental cost and the impact of fluctuations on the cost. So we established a comprehensive risk-based transmission pricing model for long-distance transmission of wind power, using wind power in Gansu as an example to verify the validity of the model. Wind power transmission in Gansu Province is typical and representative for China, because the wind resource in Gansu Province is rich but the wind power bases are far from load centres. It needs long-distance transmission for wind power, also large costs. By calculating the wind power grid connection costs and the long-distance transmission tariff in the case of Gansu Province, we find that the access grid connection cost is much higher than the allowance standard that was established by the government and that the comprehensive transmission pricing model has widespread applicability. The aim of this case study was to solve the problem of transmission tariffs for large-scale wind power in western Gansu Province in China and also for other areas which have similar problems. The results from this analysis lead to the following policy proposals:

(1) China should adjust the level of transmission tariffs for large-scale wind power in western Gansu Province based on the real transmission cost of wind power.
(2) To calculate the transmission cost of wind power, the incremental costs borne by the power system should be considered, including the fixed and variable elements of the cost, the appropriate risk-adjusted value according to the risk of fluctuations in the costs should also be added to achieve a complete consideration of the transmission costs.
(3) The "cost plus return" method should be considered for determining the electricity transmission pricing model, in the absence of a competitive power market. The transmission price must include compensation for depreciation, operation and maintenance costs, and also a reasonable return on investment, in order to offer an effective incentive and guidance mechanism for enterprises' business development.
(4) The long-distance transmission tariff for large-scale wind power should implement a two-part electricity transmission pricing system, in order to eliminate the volatility risk inherent in each simple allocation method, and the fixed and variable characteristics of the transmission cost.

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